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CRYOGENIC COMBUSTION LABORATORY

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I. Research Objectives and Potential Impact on Propulsion

The objective of the current effort is to establish a major experimental laboratory within the NASA Propulsion Engineering Research Center for studying fundamental processes such as mixing and combustion under liquid rocket engine conditions. The capability of this laboratory will include operation using a variety of fuel and oxidizer systems including liquid oxygen and liquid hydrocarbons. In addition to providing the proper facilities for supplying and controlling these fuels and oxidizers, a specific effort is being made to provide a state-of-the-art diagnostic capability for combustion measurements. In particular, optical and laser-based techniques are being emphasized for measurements of species, velocity, temperature, and spray characteristics.

The laboratory is to provide the necessary experimental capabilities for studies conducted within the Center in the area of combustion instability, liquid jet breakup, spray and droplet combustion, supercritical combustion phenomena, materials studies and nozzle flow characterization. The flow and test stand designs emphasize an approach which provides a flexible environment to accommodate a wide range of experiments while providing for convenient future expansion as new research directions emerge.

The Cryogenic Combustion Laboratory is intended to impact space propulsion engineering in a two-fold manner. Experiments conducted in the laboratory are aimed at providing benchmark data on a variety of important liquid rocket combustion processes. A clear need for the development of such data bases for model validation has been recommended in several recent JANNAF workshops. Sub-scale studies utilizing laser-based diagnostic approaches offer a great potential for obtaining new measurements under realistic operating conditions. It is precisely these types of studies which the present laboratory effort is aimed at emphasizing.

The second impact of the current program involves the training of graduate students who participate in the research projects conducted within the laboratory. These students will be exposed to studies involving fuels and oxidizers similar to present operational systems, investigated under conditions applicable to realistic operation. The utilization of sophisticated diagnostic approaches for measurements conducted under combustion conditions will also provide a valuable training experience for the students who will assume positions in leading industrial and government laboratories. Thus, the present laboratory development effort addresses two of the major needs of space propulsion engineering: new fundamental studies of liquid rocket engine phenomena and production of well-trained engineers to engage in future space propulsion activities.

II. Current Status and Results

During the past year, significant progress has been made in the establishment of the Cryogenic Combustion Laboratory, which had its first test firing using the gaseous hydrogen and oxygen system. This test firing was achieved on schedule and marks one of the major milestones in this project. Future work will proceed on a dual track basis pursuing new experimental results while concurrently adding to the capabilities of the laboratory. Specifically, liquid oxygen and hydrocarbon capabilities are planned to be added in the near future.

The general arrangement and capabilities of the Cryogenic Combustion Laboratory will be reviewed briefly in the remainder of this section. The Cryogenic Combustion Laboratory, space for which was made available to the NASA Propulsion Engineering Research Center in March, 1989, occupies a three-room complex which includes a reinforced concrete test cell (see Figure 1). The test cell is complemented by two adjacent rooms which serve as the instrumentation and control rooms. The control room contains the equipment necessary to operate the test facility. This room is isolated from the test cell during all test run sequences and is equipped with a hydrogen detection system as an added level of safety. The entire system has been designed to operate remotely using pneumatic and/or motorized actuated systems. The design of the fuel and oxidizer supply system closely follows that of an existing facility (Cell 21) located at the NASA Lewis Research Center (LeRC). Personnel at NASA LeRC kindly provided facility drawings and parts lists which greatly aided in the laboratory's development. Additional advice and guidance in the planning of the laboratory has been provided by Marshall Space Flight Center, Rocketdyne, Air Products, the Astronautics Laboratory (Air Force Systems Command) and Aerojet, and their input is gratefully acknowledged.

The operation of the test facility presently allows for operation with gaseous oxygen and gaseous fuels (hydrogen and methane have been used to date). The maximum operating pressure is approximately 1500 psi, a limit imposed by the present fire valve. The flow system has been designed to provide a maximum flow rate of 0.1 lbs/s of oxygen. This has been decided to be adequate for the present sub-scale studies for which this laboratory is intended. The sequencing of all combustion test firing is controlled by a Modicon sequencer which provides real time fault detection for run monitoring and shutdown. System testing of the entire flow system was achieved using a rocket igniter constructed by the NASA LeRC. This unit has been widely used at the NASA LeRC and represented a known test engine from which to evaluate the operation of gaseous flow system and control equipment. Successful firings of this igniter occurred near the end of December, 1989, and have periodically continued through March, 1990. Both hydrogen/oxygen and methane/oxygen test runs have been conducted. This extensive series of tests has provided a suitable basis for assuring the adequacy of the safety systems, run procedures and general operation of the laboratory. Figure 2 shows a photograph of one of the test firings of the rocket igniter burning methane/oxygen.

Propellant storage area

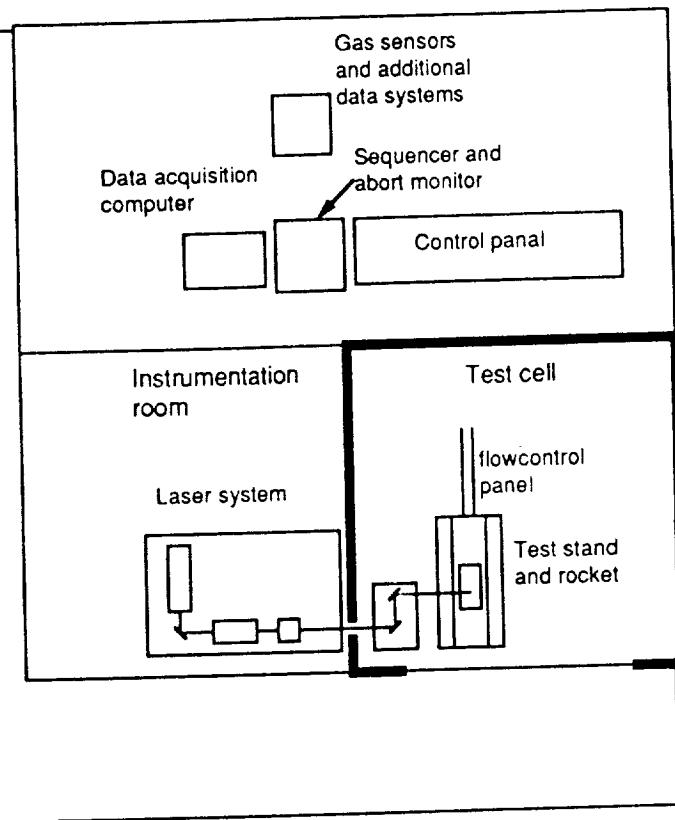


Figure 1. Schematic representation of the Cryogenic Combustion Laboratory Complex: TestCell, Instrumentation Room and Control Room

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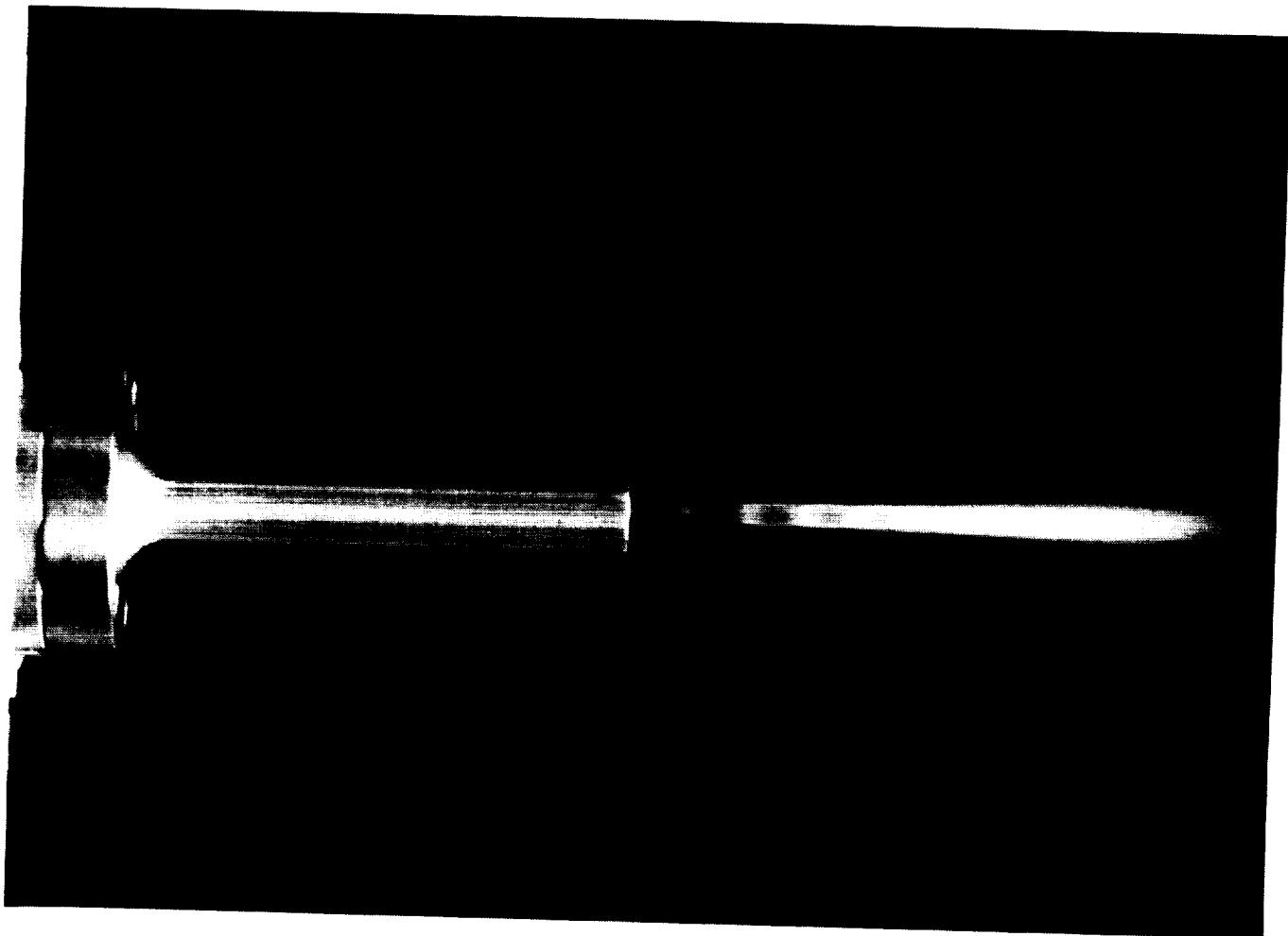


Figure 2: Rocket Test Igniter Firing: Methane oxygen test at an equivalence ratio of 0.56. Oxidizer mass flow rate of 0.01 lbm/sec, fuel mass flow rate of 0.0014 lbm/s. Chamber pressure 85 psia.

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In addition to the progress achieved in the gaseous flow systems for the laboratory, efforts have been initiated to add a liquid oxygen capability. A suitable cryogenic oxygen storage tank has been obtained. This tank was originally associated with Prof. L. Crocco's laboratory at Princeton University and has been kindly made available to the NASA Propulsion Engineering Research Center by Princeton. The initial design plans for the liquid oxygen flow system have been completed and the components are presently being ordered.

Future plans for experiments using the Cryogenic Combustion Laboratory include imaging studies of the combustion processes within the rocket chamber. These studies will initially concentrate on planar (i.e. two-dimensional) imaging of OH radical concentration profiles in a hydrogen/oxygen rocket. Further studies of spray combustion processes are also planned using both planar and point measurement techniques. Efforts to establish the necessary diagnostic capabilities have also progressed substantially. Both a pulsed Nd-Yag and a cw argon ion laser system have been acquired during the last year for use in these studies. Diagnostics for providing two-dimensional imaging of droplets in a combusting environment are presently being developed in a separate laboratory for use with these lasers. Additionally, a phase doppler particle analyzer has recently been added for additional droplet sizing capabilities. A dye laser will also be available shortly to give additional wavelength selection capabilities.

In summary, the first phase of the Cryogenic Combustion Laboratory has been successfully completed. Progress on applying the present test capability to new measurements and studies has been initiated. Planning to complete the second major operational goal, liquid oxygen capability, is proceeding on schedule. Additionally, a solid diagnostic basis is being developed to complement the test capability of the laboratory with state-of-the-art diagnostic techniques.

III. Proposed Work for Coming Year

During the coming year, the proposed work will focus on augmenting the Cryogenic Combustion Laboratory to include liquid oxygen capability. The present design specifies a LOX mass flow rate of 1 lb/s which significantly increases the present capabilities over that of the gaseous oxygen system. The intent of achieving this flow rate is based on a desire to adequately study liquid rocket injector elements. Both uni-element and multi-element (three to five elements) studies should be feasible with the planned flow system. Initial testing of this system will be accomplished using the current hydrogen fuel system, and initial tests are planned for the end of the present calendar year.

As a concurrent effort, the first two of a series of laser diagnostic techniques are presently under development. These techniques involve planar laser imaging of OH and spray visualization and sizing. Both techniques are intended to provide spatially extensive (i.e. two-dimensional fields) under high temporal resolution conditions. The OH diagnostics will utilize the Center's present Nd-Yag laser in conjunction with a recently acquired dye laser and wavelength doubling system. The necessary data acquisition and solid-state camera system are presently being specified. Initial development of the OH visualization system will be accomplished using a flat flame burner before application to a uni-element injector, rocket combustor environment. Presently, several design approaches are being pursued for developing an appropriate optically accessible rocket chamber. Initial measurements of OH in such a rocket combustor are planned for the coming year of the program. These initial rocket studies will utilize the present gaseous hydrogen and oxygen flow system. Use of this system provides the simplest system for achieving the planned measurements, eliminating interference from droplets or soot particles. The intention of the present program is to examine the OH distribution as a qualitative indication of the combustion zone distribution in the combustor. Future work is intended to examine the effects of oscillating pressure fields on that distribution. However, these efforts go beyond the present program for the Cryogenic Combustion Laboratory which emphasizes development of the basic laboratory and diagnostic capability to support the space propulsion research interests of the Center.

In a similar approach, a planar laser imaging approach for spray diagnostics is being developed as part of a separate program on rocket spray combustion phenomena (H.R. Jacobs and R.J. Santoro, "Spray Combustion Under Oscillatory Pressure Conditions".) This technique utilizes the ratio of scattered light obtained at two polarization orientations to provide a measure of the droplet size. Evaluation of this diagnostic approach is presently proceeding in a non-combusting environment. Based on the results of these studies, this approach will be implemented for the study of liquid oxygen sprays in coaxial injector elements.

In summary, the proposed effort for the current year involves both a continued development of the Cryogenic Combustion Laboratory along with the initiation of basic propulsion studies in simple rocket combustors. These developments represent the realization of a laboratory capability needed for future Center research efforts.